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Potential Distribution in CMOS Semiconductors

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Method of Measuring the Two-Dimensional Potential Distribution in CMOS Semiconductor Components.

The invention relates to a method of measuring the two-dimensional potential distribution in CMOS semiconductor components and of determining the two-dimensional doping distribution.

Modern semiconductor component structures in the sub-micrometer range require the implantation and manipulation of doping elements in silicon semiconductor components at a lateral and vertical precision in the nm range. The two-dimensional definition of such doping profiles in actual components having a spatial resolution of this magnitude is of great significance for optimizing physical models for the numeric simulation of the complex fabrication processes and for the analysis of errors in real processed components. To date, no method of measuring the two-dimensional potential distribution in CMOS semiconductor components and of determining the two-dimensional dopant distribution has become known which makes possible a direct image formation of such two-dimensional doping profiles in a transmission electron microscope (TEM). WO 98/12544 A describes the determination of dopant distribution at a precision in the nm range by use of an electron microscope. U.S. Patent 5,523,700 discloses a method of quantitatively determining the doping profile by making use of local changes in capacity at the surface of a semiconductor material. Often, because of preparation artefacts or surface segregations, the measured doping distribution at the surface of a sample is not representative of conditions within the solid body. In order to quantify a local change in capacity as a doping distribution, it is necessary to model the local capacity. This, however,

requires elaborate electrical simulations.

It is an object of the invention to propose a method of measuring the two-dimensional potential distribution in CMOS semiconductor elements and of determining the two-dimensional doping distribution in which it is possible to form a direct image of the two-dimensional doping distribution and of the two-dimensional potential distribution in a transmission electron microscope.

The method in accordance with the invention is based upon the use of electron holography and, more particularly, electron off-axis holography in a transmission electron microscope. Electron holography permits two-dimensional measurements of the phase of the electron wave in the transmission electron microscope. The phase distribution is directly proportional to the two-dimensional potential distribution in the spatial charge area of a pn-junction in semiconductor structures. The potential distribution is determined by electron holography. The method according to the invention of measuring the two-dimensional potential distribution in CMOS semiconductor components and of determining the two-dimensional dopant distribution using electron holography for measuring the phase of an electron wave in a transmission electron microscope with a lateral accuracy in the nm range is carried out by the method steps of:

- generating a planar electron wave;
- modulating the planar electron wave as a result of transmission through a thinned cross-sectional sample of the semiconductor component;
- enlarging the modulated image wave by means of an objective lens;
- superposing the enlarged image and a planar reference wave by means of an electron bi prism;
- registering the generated electron hologram by means of a digital CCD camera, photo plates or other detector systems;
- extracting the phase of the image wave by means of a Fourier analysis; and

- measuring the two-dimensional potential distribution from the phase image.

The two-dimensional dopant distribution in CMOS structures and, especially, of CMOS transistor structures is determined and/or physical models for the simulation of the fabrication process are optimized by comparison with numerical simulations of the fabrication process.

The characteristics of the invention will become apparent, aside from the claims, from the description and the drawings. An embodiment of the invention has been shown in the drawing and will be described in greater detail hereinafter.

Fig. 1 depicts the principle of electron holographically determining the potential distribution. Initially, a so-called thinned cross-sectional sample is prepared by mechanical grinding and ion-etching to render it transparent to electron waves. This has to be fabricated with a target preparation in such a way that in the immediate vicinity of about 100 nm to 500 nm of the transistor to be examined there is generated a "hole" for the required planar reference wave 6 which must not be guided through the sample. The thickness of the sample near the transistor to be examined should be within an optimum range of between 50 nm and 500 nm. A planar electron wave 1 in the TEM provided with an electron bi-prism 4 is phase modulated by potential distribution as it is transmitted through a thinned cross-sectional sample of the pn-junction of a CMOS transistor 2. This modulated wave is called "modulated image wave 3". A planar reference wave 6 is superposed on the modulated image wave 3 which has been enlarged by an objective lens 5, by means of the electron bi prism 4. The generated electron hologram 7 is registered by a digital CCD camera 8. Amplitude and phase of the image wave 3 are extracted by Fourier analysis. The two-dimensional potential distribution is determined on the basis of the phase image. The phase image

is directly proportional to the potential distribution. Combining the image of amplitude and phase additionally permits a localized definition of the thickness of the sample.

The ensuing determination of the two-dimensional dopant distribution is carried out by adjusting the potential distribution caused by the dopant distribution to the potential distribution measured by the electron holography. To this end use is made of numeric simulations of the potential corresponding to the dopant distribution.

By the present invention, a method of measuring the two-dimensional potential distribution in CMOS semiconductor components and of determining the two-dimensional dopant distribution has been set forth on the basis of a concrete embodiment.